Analysis of Revenue Distribution of Assembly Building under EPC Model Based on Entropy Weight-TOPSIS Improved Shapley Value

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Prefabricated construction has rapidly developed due to its efficiency and environmental benefits. With the widespread application of the EPC (Engineering, Procurement, and Construction) model, achieving fair and reasonable distribution of profits in prefabricated construction projects under this model has become an urgent issue that needs to be addressed. In response to the limitations of the traditional Shapley value method, this paper introduces input factors, technological factors, and management factors to develop an improved profit distribution model based on entropy-weighted TOPSIS and the Shapley value. A case study is presented to validate the model. Results of the study show that the improved Shapley value method balances the earnings with the actual contribution and achieves a fair and reasonable earnings distribution.

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Keywords: EPC; Prefabricated construction; Shapley value method; Profit distribution

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INTRODUCTION

Productivity is a challenge in the construction industry, and it is commonly initiated by fragmentation (Sholeh *et al.* 2020). The Engineering, Procurement, and Construction (EPC) model is an integrated project management approach that combines design, construction, and procurement. Its characteristics of integration and efficiency have led to widespread application in the construction industry. The construction supply chain is one of the possible solutions adopted to increase productivity (Sholeh and Fauziyah 2018). Prefabricated construction under the EPC model can further enhance the quality and efficiency of building projects. However, these projects involve multiple stakeholders with varying degrees of contribution, making the fair and reasonable distribution of profits a pressing issue that necessitates a robust profit distribution mechanism.

There are various methods to study the benefit distribution in evolutionary game cooperation, such as the fair entropy method, the Nash bargaining model, and the Shapley value method, which is the most widely used in the field of benefit distribution. It allocates benefits according to the size of each participant's contribution to the overall cooperation, avoiding the traditional equal distribution (Liu *et al*. 2006). It can be applied to various industries. For example, Ma and Wang (2006) used the Shapley value method to solve the benefit distribution problem among supply chain partners). Yi and You (2021) used the Shapley value to analyze the benefit distribution of shareholders in the comprehensive pipeline PPP project. Although the Shapley value method avoids the traditional equal distribution, it also has certain drawbacks, as it assumes that all influencing factors are equal (Song *et al*. 2021). Based on this, scholars have proposed an improved Shapley value method for the fair distribution of the cooperation profits of each alliance. For instance, Zhang *et al*. (2023) introduced factors such as risk bearing and resource investment on the basis of the traditional Shapley value and constructed a green supply chain benefit distribution model for prefabricated buildings based on the improved Shapley value method. Chen and Wang (2023) considered factors such as the degree of investment, risk sharing, and contribution, and used the DEMATEL method to construct a D-ANP benefit distribution model. Sang and Qin (2023) considered risk factors and used the cloud centroid method to construct an improved Shapley value's full-process engineering consulting consortium benefit distribution model. Chen and Yang (2021) introduced factors such as cooperation contribution rate, cost bearing, and risk bearing, and used the AHP-GEM method to determine the weight of influencing factors. constructing an improved Shapley value benefit distribution for the prefabricated building industry chain. Wibowo and Sholeh (2015) described performance measurement using the Supply Chain Operations References (SCOR), which analyzes the supply chain management of a contractor.

Through the above analyses, previous studies have quantified the influencing factors to determine the distribution weight, proposed an improved Shapley value benefit distribution model, and applied it to various fields. However, its application in prefabricated buildings under the EPC model is relatively rare, and there are drawbacks due to the incomplete consideration of factors. Therefore, it is necessary to improve the benefit distribution method for prefabricated buildings under the EPC model.

Improved Shapley value gain distribution analysis based on entropy weight-TOPSIS refers to the introduction of entropy weight method and TOPSIS method to determine the gain distribution coefficients of each participating subject in cooperative game theory. The method aims to assess the contribution of each participant more accurately and to realize the fair distribution of cooperative gains.

This study comprehensively considered the influencing factors, used the entropy weight TOPSIS method to determine the correction factor, and designed an improved Shapley value benefit distribution model, which embodies the scientific and rational nature of the benefit distribution plan in practical terms.

The study model is shown in Fig. 1.

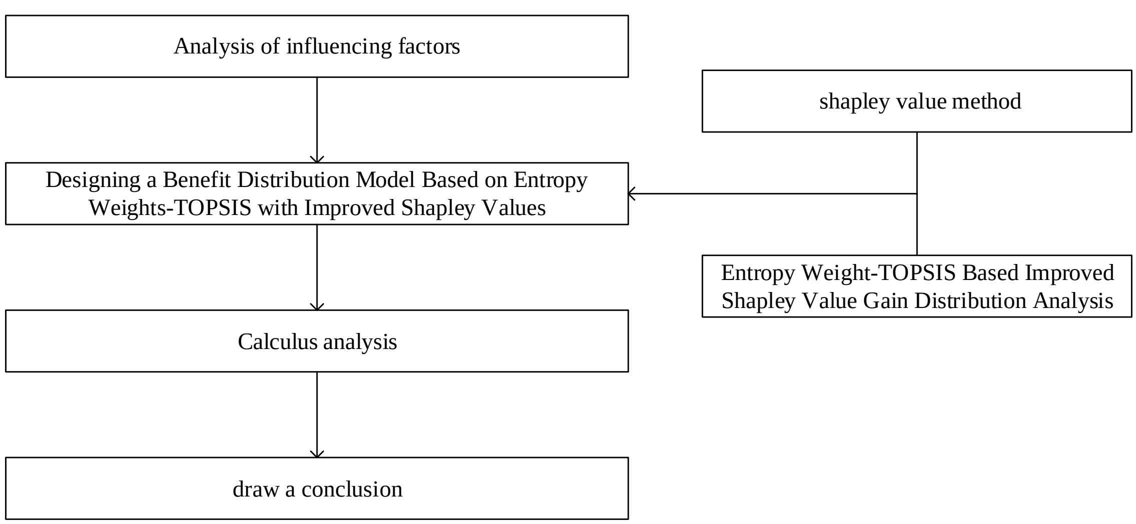

Fig. 1. Study model

EXPERIMENTAL

Analysis of Factors Affecting Benefit Distribution in Prefabricated Building under the EPC Model

Through literature review and data analysis, this article categorized the factors affecting benefit distribution into input factors, technical factors, and management factors.

Input factors

Input factors are key determinants of benefit distribution in prefabricated buildings under the EPC model. The design party, as the project planner, primarily invests in scheme design, optimization, and consulting services. The construction party, as the main executor of the project, invests in labor, equipment, raw materials, *etc*., and its input will affect the quality and progress of the project. The supplier's input is mainly reflected in the timely supply of raw materials, ensuring quality and quantity, and cost control.

Technical factors

Technical factors are significant in influencing the distribution of benefits in prefabricated buildings under the EPC model. The design party's level of technical expertise is demonstrated through the innovation, optimization, and service capability of their design solutions. The construction party's technical proficiency is reflected in construction processes, technology, and project management. A certain level of technical expertise and efficient management contribute to reducing construction costs and enhancing efficiency. The supplier's technical level is evident in the research and development of materials and production processes; advanced technology enables the production of higher-quality materials at a lower cost.

Management factors

The management capabilities of all participating entities directly affect the overall operational efficiency and cost control of the project. The design party's management skills are primarily manifested in project planning, scheme formulation, and communication and coordination throughout the entire process. The construction party's management skills are reflected in organizing construction, controlling progress, and managing costs to ensure the smooth implementation of the project. The supplier must ensure the quality of material supply and the timeliness of distribution to facilitate the smooth execution of the project.

RESULTS AND DISCUSSION

Improved Shapley Value Based on Entropy Weight-TOPSIS Model for Revenue Sharing

Shapley value method

In 1953, American economist Lloyd Shapley proposed the Shapley value method, which is a method to measure the distribution of benefits in multi-subject cooperation. The theory avoids egalitarianism in distribution. It is more rational and fair, reflecting the process of mutual games of the subjects (Shapley 1953).

The value of benefit distribution of each participating subject in the cooperative alliance is called Shapley value, which is noted as follows,

$$\varphi_i(v) = \sum_{s \subseteq Si} w(|s|)[v(s) - v(s/i)] \,, \quad i = 1, 2, ..., n \tag{1}$$

$$w(|s|) = \frac{(n-|s|)!(|s|-1)!}{n!} \tag{2}$$

where $v(s) - v(s/i)$ refers to the contribution made by the subject in the cooperation. This cooperation has $(n - |s|)!(|s| - 1)!$ ways of appearing, and the probability of each appearance is $w(|s|)$.

The expected value of the contribution made by the subjects involved in the assembly building under the EPC mode is the Shapley value, and the distribution of benefits among the subjects can be regarded as the problem of distributing the benefits of the multi-people cooperation countermeasures, which can be solved by the Shapley value method.

Entropy Weight-TOPSIS Based Improved Shapley Value Gain Distribution Analysis

To ensure the fairness and reasonableness of the distribution of the proceeds of each participating subject of the assembly building under the EPC mode of the system, the article adopts the entropy weight-TOPSIS subjective-objective combination of methods to determine the comprehensive correction coefficients for the distribution of the proceeds (Zhang and Gao 2020). Entropy weight method determines the weights according to the discrete degree of the index, which has better objectivity. The TOPSIS method is a sorting method close to the ideal solution to achieve the comprehensive evaluation of the weight indexes. The entropy weight TOPSIS method combines the advantages of the entropy weight method and the TOPSIS method, taking into account both the objectivity of the weight determination and the comprehensiveness of the evaluation process. This enables the entropy weight TOPSIS method to achieve better results in practical application, and the allocation results are more in line with the actual situation.

(1) Relevant experts and scholars score the evaluation indicators of the participating subjects of party i and construct an evaluation matrix with the corresponding value of x_{ij}, where x_{ij} represents the evaluation value of the ith influence factor of the subject of party j, $i = 1, 2, \ldots, n$, $j = 1, 2, \ldots, m$. The matrix X is normalized to obtain the normalized matrix P as:

$$X = \begin{bmatrix} x_{11} & x_{12} & x_{1m} \\ \cdots & \cdots & \cdots \\ x_{n1} & x_{n2} & x_{nm} \end{bmatrix} \tag{3}$$

$$P_{ij} = \frac{X_{ij}}{\sum_{i=1}^{n} x_{ij}} \tag{4}$$

(2) Entropy weighting method to determine impact factor weights

$$E_j = \frac{1}{\ln n} \sum_{i=1}^{n} (y_{ij} * \ln y_{ij}) \tag{5}$$

According to the definition of information entropy, the greater the role of this evaluation factor, the greater the information entropy, the smaller the weight; conversely the smaller the information entropy, the greater the weight. The weight μ_j of the j^{th} influence factor is:

$$g_i = 1 - E_j \tag{6}$$

$$\mu_j = \frac{g_j}{\sum_{j=i}^{m} g_j} \tag{7}$$

(3) The TOPSIS method determines the distribution correction factor for each participating subject. The procedure is as follows:

Calculate the weighting matrix Z based on the entropy weights to obtain a vector of positive ideals Z^+ and a vector of negative ideals Z^-.

$$Z^+ = \left\{ (\max_i(Z_{ij}),\ j \in j_1), (\min_i(Z_{ij}),\ j \in j_2) \middle| i = 1, 2, ..., m \right\} \tag{8}$$

$$Z^- = \left\{ (\min_i(Z_{ij}),\ j \in j_1), (\max_i(Z_{ij}),\ j \in j_2) \middle| i = 1, 2, ..., m \right\} \tag{9}$$

where j^+ refers to the positive indicator, *i.e.*, the preferred programme, and j^- refers to the negative indicator, the biased bad programme.

The distance from the evaluation value of each participating subject to the positive and negative ideal values is denoted by d_i^+ and d_i^-, respectively.

$$d_i^+ = \sqrt{\sum_{j=i}^{m} (Z_{ij} - Z_j^+)^2} \tag{10}$$

$$d_i^- = \sqrt{\sum_{j=i}^{m} (Z_{ij} - Z_j^-)^2} \tag{11}$$

The proximity of the evaluation value vector of each participating subject to the ideal value is calculated, denoted by S_i, and normalization is done to obtain the correction coefficient $\Delta\beta_i$.

$$S_i = \frac{d_i^-}{d_i + + d_i^-} \tag{12}$$

$$\Delta\beta_i = \beta_i - \frac{1}{m} \tag{13}$$

Finally, the benefit distribution of the improved Shapley value method is:

$$\varphi'_i(v) = \varphi_i(v) + v(I) * \Delta\beta_i \tag{14}$$

Calculus analysis

Taking an assembly building in EPC mode as an example, the project involves three subjects including the designer *A*, the constructor *B*, and the supplier *C*. When not cooperating, each of them obtains the base revenue of V_A = 350, V_B = 400, and V_C = 250. When two parties cooperate, the revenue is V_{AB} = 860, V_{AC} = 700, V_{AC} = 700, and V_{BC} = 750; when three parties cooperate, the revenue is V_{ABC} = 1400. Tables 1 through 3 show the income distribution results before the Shapley value method of each party is corrected using the above model.

Table 1. Distribution of Benefits to Designers *A*

S	*A*	*AB*	*AC*	*ABC*
V(*S*)	350	860	700	1400
V(*S/A*)	0	400	250	750
V(*S*) - *V*(*S/A*)	350	460	450	650
|*S*|	1	2	2	3
ω(|*S*|)	1/3	1/6	1/6	1/3
ω(|*S*|)[*V*(*S*) - *V*(*S/A*)]	350/3	460/6	650/6	650/3

Table 2. Distribution of Benefits to Constructor *B*

S	*B*	*AB*	*BC*	*ABC*
V(*S*)	400	860	750	1400
V(*S/B*)	0	350	250	700
V(*S*) - *V*(*S/B*)	400	510	500	700
|*S*|	1	2	2	3
ω(|*S*|)	1/3	1/6	1/6	1/3
ω(|*S*|)[*V*(*S*) - *V*(*S/B*)]	400/3	510/6	500/6	700/3

Table 3. Distribution of Benefits to Supplier *C*

S	*C*	*AC*	*BC*	*ABC*
V(*S*)	250	700	750	1400
V(*S/C*)	0	350	400	860
V(*S*) - *V*(*S/C*)	250	350	350	540
|*S*|	1	2	2	3
ω(|*S*|)	1/3	1/6	1/6	1/3
ω(|*S*|)[*V*(*S*) - *V*(*S/C*)]	250/3	350/6	350/6	540/3

Therefore, the profit of the design side *A* is = 350/3 + 460/6 + 650/6 + 650/3 = 485, and the profit of the construction side *B* is = 400/3 + 510/6 + 500/6 + 700/3 = 535, and the profit of the supply side *C* is = 250/3 + 350/6 + 350/6 + 540/3 = 380.

Assuming that relevant experts and scholars have been invited to score the evaluation indicators of the three main parties, the normalized results are as follows:

$$Y = \begin{bmatrix} 0.357 & 0.417 & 0.364 \\ 0.357 & 0.25 & 0.364 \\ 0.286 & 0.333 & 0.272 \end{bmatrix} \quad (15)$$

Calculated by entropy weight method, the information entropy value, information utility value, and weight of each index are obtained as shown in Table 4. Positive and negative ideal solutions are derived using TOPSIS analysis, which leads to the relative proximity of each participating subject based on entropy weight TOPSIS, as shown in Table 5.

Table 4. Weights of Each Influencing Factor

Influencing Factor	Weighting
Input factors	38.79%
Technical factors	37.23%
Management factors	23.97%

Table 5. Relative Closeness Based on TOPSIS

Design Party	Relative Closeness
A	0.470
B	0.530
C	0.494

The final revenue sharing factors were calculated as follows:

$$\Delta\beta_A = \beta_A - 1/3 = -0.0187 \quad (16)$$

$$\Delta\beta_B = \beta_B - 1/3 = 0.0214 \quad (17)$$

$$\Delta\beta_C = \beta_C - 1/3 = -0.0027 \quad (18)$$

If $\Delta\beta_B > 0$, it indicates that the participating subject should receive a higher benefit; $\Delta\beta_A$ and $\Delta\beta_C < 0$, it indicates that the participating subject has not paid as much as the current level of benefit that it should receive, and that the distribution of its benefit should be reduced and compensated to the other participating subjects.

The final revenue allocation value of the tripartite subjects is obtained as follows:

$$\varphi'_A(v) = 485 + 1400*(-0.0187) = 458.8 \quad (19)$$

$$\varphi'_B(v) = 535 + 1400*0.0218 = 565 \quad (20)$$

$$\varphi'_C(v) = 380 + 1400*(-0.0026) = 376.2 \quad (21)$$

The profit distribution values obtained by the tripartite subjects according to the modified Shapley value method are compared with the original model to validate, $\varphi'_A(v) + \varphi'_B + (v)\ \varphi'_C(v) = 1400$. The improved Shapley value method is calculated correctly, and the total return remains unchanged. The comparison of the profit distribution of the three subjects before and after the modified Shapley value is shown in Table 6.

Table 6. Comparison of Benefits Before and After Improvements

	Pre improvement	After improvement
Designer	485	458.8
Constructor	535	565
Supplier	380	376.2

The main body of revenue allocation of assembled building under EPC mode has designer, constructor, and supplier, so the default allocation weight of the traditional Shapley value is 1/3, and after the improvement of the Shapley value, the revenue of the designer and supplier is relatively reduced, and the revenue of the constructor is relatively enhanced. Because in the assembly building project under EPC mode, the construction side pays more than the design side and the supply side for the greater impact on the distribution of benefits, so the combined weight of the design side and the supply side is lower than the default 1/3, while the construction side's combined weight in the three influencing factors is higher than 1/3, so the construction side should be compensated to a certain extent, and the improved Shapley's value method is more fair and reasonable.

CONCLUSIONS

This paper focused on the revenue allocation of assembled buildings under the engineering, procurement, and construction (EPC) mode, for the limitations of the traditional Shapley value method of allocation.

1. The study introduced the input factors, technical factors, and management factors. It used the entropy weight-TOPSIS subjective-objective combination of methods to determine the comprehensive correction coefficients for the allocation of revenues, and it constructed a revenue allocation model for assembled buildings with improved Shapley value. This approach was illustrated by means of a case study.
2. The results of the study showed that the improved Shapley value method balances the earnings with the actual contribution and achieves a fair and reasonable earnings distribution.

Based on these conclusions, the article makes the following recommendations:

A. Improve the revenue distribution mechanism:

Assembled buildings involve multiple stakeholders with different interests, so a more perfect, scientific, and reasonable revenue allocation mechanism should be established.

B. Strengthen information sharing and communication:

The establishment of an information sharing platform to promote the exchange of information between the parties to reduce information asymmetry.

C. Strengthen policy guidance and support:

Introduce relevant policies to encourage and support the development of assembled buildings. For example, it should provide incentives such as tax concessions and capital subsidies to reduce the cost burden of enterprises. At the same time, strengthen the supervision and guidance of assembly building projects to ensure the smooth implementation of the project and the fairness of benefit distribution.

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